Experiments Study on the Performance of Automotive Exhaust Muffler

Guo-quan XIAO* and Guang-dian LIN

School of Mechanical & Automotive Engineering, South China University of Technology, Guangzhou, China, 510640

*Corresponding author

Keywords: Muffler, Pressure loss, Insertion loss, Aerodynamic noise, Engine bench test.

Abstract. Firstly, a performance test system was established for exhaust muffler based on the existing engine bench and physical layout of vehicle exhaust system. Secondly, the experimental data of original muffler exhaust back-pressure, noise of exhaust and tailpipe were recorded, and the pressure loss and insertion loss were computed. An optimized design scheme was proposed and the verification experiment was conducted according to previous results and design requirements. Finally, the experimental results show that exhaust back-pressure is reduced at all engine speeds, especially at high speed (4800rpm or above) reduced by about 4kPa; and exhaust noise decreases obviously, the insertion loss reached 27 dB (A) at low speed (between 1000 and 3200rpm), the exhaust noise declined by about 3dB (A) at high speeds (4800rpm or above).

Introduction

Muffler is a widely used device to reduce exhaust noise of automobiles. The theoretical design of muffler is complex [1-6], and the experimental research of muffler is more and more important. Desantes, etc. established a test device to study of muffler noise at ambient temperature [7]; Chumacher built the exhaust muffler test-bed of the automobile engine, and studied the noise attenuation performance of various muffler [8]; Jebasinski established the measuring device of the airflow regeneration noise and the acoustic loss without airflow of the muffler [9]; Takashi Yasuda, etc. measured the transient noise of exhaust in anechoic chamber [10]. In the domestic, Liu Yongqiang, etc. designed sound insulation cover to isolate background noise for exhaust noise measurement, and verified the measurement method through the bench test [11]; Yu Fei, etc. carried out noise measurement of the steady and rapid acceleration process of the automobile exhaust muffler system, and the exhaust pipe was introduced into the semi anechoic chamber [12]. The above research showed that the performance test of muffler is gradually from cold state to hot state, from steady state to transient state, and the control methods of flow rate, flow rate and temperature of exhaust system are explored continuously. In order to consider the influence of the actual engine conditions on the noise attenuation characteristics of the muffler, a test bench which meet the test requirements is built to test the performance of the muffler.

The paper is organized as follows: the next section describes the muffler performance test system. The following section present muffler performance test, and the pressure loss and insertion loss were computed. An optimized design scheme was proposed in the results and discussions section. Conclusions are given in the final section of the paper.

Muffler Performance Test System

Based on the existing engine bench, according to GB/T 4759-2009 "internal combustion engine exhaust muffler measurement method" [13] and QC 631-2009 "automobile exhaust muffler assembly technical conditions and test methods", the exhaust muffler performance test system is established, the relative position of each equipment and instrument installation is shown in Figure 1.

As shown in Figure 1-2, according to the actual loading state a exhaust muffler performance test system is established based on the POWERLINK engine test bench which mainly includes GW160
type electric eddy current dynamometer, POWERLINK FC3000 engine automatic measurement and control system, FC2022 multi-channel data acquisition instrument and the actual engine for loading.

![Diagram](image)

Figure 1. Schematic diagram of performance test system for exhaust muffler.

(with ECU), the exhaust system which mainly includes the two three-way catalytic converters, the two mufflers and the exhaust pipes, and the other long cylindrical empty tubes, and the AVANT MI-7008 dynamic signal Analyzer, fuel consumption analyzer, multi-channel Agilent acquisition system.

**Muffler Performance Test**

The performance evaluation index of muffler mainly includes pressure loss and insertion loss. The pressure loss characterizes the exhaust resistance of the muffler, which mainly reflects the influence of the muffler on the engine power consumption. The insertion loss reflects the noise attenuation performance of the muffler, and it is related to the characteristic of the radiated sound source and the exit impedance of the muffler to be measured.

**Test Methods**

Temperature measurement method: the high-temperature PT100 thermocouples are installed by drilling and welding threaded holes at the downstream 75mm of the engine exhaust manifold outlet and about 50mm of the inlet and outlet of three-way catalyst and the muffler, and the temperatures are detected through multi-channel Agilent data acquisition system.

Pressure measurement method: the pressure sensors are installed by drilling and welding threaded holes at about 20mm of the inlet and outlet of the same long cylindrical empty tube and the mufflers, which the high-temperature exhaust is drawn through the copper tube, and it is introduced into the pressure transmitter of the data acquisition instrument by the PVC pipe (200 °C) which is connected with the copper pipe after cooling. Then the pressure of each measuring point is measured by the data acquisition system. The calculation formula for the pressure loss as follows (Eq. 1).

\[
\Delta P_{ex} = P_{ex1} - P_{ex2}
\]

where, \( P_{ex1} \) -The pressure of with the muffler;
\( P_{ex2} \) -The pressure of only with the cylindrical empty tube;
\( \Delta P_{ex} \) -The pressure loss(kPa).

Noise measurement method: The engine exhaust are leaded to the open outdoor, and the laboratory wall is noise insulated with about 10cm thick sound absorption materials which they can eliminate the engine noise on the outside of the wall exhaust noise measurement. According to GB/t 4759-2009, the
noise measurement location at breeze (the wind speed less than 2m/s), near the background noise is generally lower than 50dB (A), and it is 45° [13] measurement, that is, exhaust noise microphone layout axial 45° direction of 0.5m and exhaust airflow, the microphone pointing to the exhaust port, measuring point distance from the ground height is greater than 1m.

Measurement of shell radiation noise: The microphone is placed on the surface of the exhaust tube shell 0.1±0.01 meters.

The exhaust noise and the radiation noise of the tube shell are measured by the MILLEBEM A weight sound level meter, the data are processed by AVANT MI-7008 Dynamic Signal analyzer, the noise at each engine speed and the insertion loss of the muffler is calculated as follows (Eq. 2) [14].

\[ D = L_{p1} - L_{p2} \]

where,

- \( L_{p1} \) - the exhaust noise of with empty tube;
- \( L_{p2} \) - the exhaust noise of with muffler;
- \( D \) - the insertion loss (dB)

Test Process

According to the actual loading state of the exhaust system to debug the engine and ensure that the test sensors and instruments at normal operation, the engine running parameters are stable before starting the test, and the test bench and the noise measuring equipment should be ensured to meet the test conditions before the data is collected. The test is carried out with the equivalent empty tube and the muffler respectively.

Firstly, the background noise and engine stable idle noise are measured, and then the engine's power, engine speed, fuel consumption, inlet pressure, cooling water and oil temperature are measured in turn a total of 14 operating points which it runs at the engine throttle full state, so that the engine speed stabled at the 1000r/min, and then start from the 1200r/min, every 400r/min stable once, until 5600r/min, and the engine speed error is less than ±5r/min at each test point, and the measuring time of each operating point is 30s~50s.

Results and Discussion

Exhaust Back Pressure

The exhaust back pressure are shown in Figure 2.

![Figure 2. Comparison of engine exhaust back pressure.](image)

As shown in Figure 2, the exhaust back pressure of the optimal muffler is lower than the original muffler at the whole engine speed range. At high engine speed (4800rpm or above), the exhaust back pressure is reduced more obviously, reduced by about 4-5kpa, and the exhaust back pressure difference between with muffler and with equivalent empty tube is 9kPa (appearing at 5600rpm). The power loss of the engine is reduced and the output power is increased which they compared with the original exhaust muffler system.
Exhaust Noise

There is no howling and other abnormal sound occurred during the whole test process (except the rapid deceleration process). The background noise before and after each test is 46dB (a), while the total noise level of each measuring point (except idle working condition) is higher than the background noise level at least 15dB (A), therefore, the measurement result is not corrected and the data is processed and analyzed directly. At each engine speed, the total steady noise of the exhaust port (with muffler and with equivalent empty tube) are shown in Figure 3. The insertion loss of the muffler is shown in Figure 4.

As shown in Figure 3-4 that the muffler exhaust noise sound pressure level increase as the engine speed rises. Without a muffler, the exhaust noise will reach 90dB (A) above at 1000rpm, and at a high speed it is close to 120dB (A); With a muffler, the exhaust noise are reduced at different speed, the insertion loss range is 7~32.2 dB (A), the insertion loss is the largest at 1600rpm and the insertion loss is the least at 5600rpm. At low engine speed (1000~3200rpm), the insertion loss is above 20 dB (A), in which the exhaust noise of the muffler is significantly lower than that of the original muffler, and the insertion loss is above 27 dB (A), and the noise attenuation effect is better. But at 3200rpm above, the insertion loss of the muffler is reduced rapidly, the noise attenuation effect becomes worse, at a high engine speed (4800rpm or above), the insertion loss of the original scheme is less than 10dB (A).

The radiated noise of the shell at each engine speed is shown in Figure 5.

It is shown in Figure 5 that the shell radiated noise is within the limited value at all engine speed.

Conclusion

(1) A performance test system of an automobile exhaust muffler was established, which can meet the requirements of muffler performance testing.
(2) An optimized design scheme was proposed and the verification experiment was conducted according to previous results and design requirements.

(3) The experimental results show that exhaust back-pressure is reduced at all engine speeds, especially at high speed (4800rpm or above) reduced by about 4kPa; and exhaust noise decreases obviously, the insertion loss reached 27 dB (A) at low speed (between 1000 and 3200rpm), the exhaust noise declined by about 3dB (A) at high speeds (4800rpm or above).

Acknowledgement

This research was partially supported by the National Natural Science Foundation of China (Grant No: 51375168) and Science and Technology Planning Project of Guangzhou (2014J4100014), and the experiments were supported by the Dongguan City Ming-Shi Auto Parts Co., Ltd.

References


